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Magnetic Fields Produced by Hand Held Hair Dryers, Stereo Headsets, Home Sewing Machines, and Electric Clocks

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A recent epidemiologic study reported associations between leukemia risk in children and their personal use of television (TV) sets, hair dryers, and stereo headsets, and the prenatal use by their mothers of sewing machines. To provide exposure data to aid in the interpretation of these findings, extremely and very low frequency (ELF and VLF) magnetic fields produced by a sample of each type of appliance were characterized in a field study of volunteers conducted in Washington DC and its Maryland suburbs. Questionnaire data regarding children's or mothers' patterns of usage of each type of appliance were also collected. ELF magnetic fields measured 10 cm from the nozzles of hair dryers were elevated over the ambient by a mean factor of 17 when these devices were in use. Fields near headsets being used to listen to music were not distinguishable from ambient levels except at frequencies below and well above 60 Hz and, even then, field levels were < 0.01 μT. Home sewing machines produced ELF magnetic fields that were elevated by a factor of 2.8 over ambient levels at the front surfaces of the lower abdomens of mothers. Estimated mean daily times of usage of hair dryers, stereo headsets, and sewing machines were 2.6, 19, and 17 minutes, respectively. These data and previously published data on TV sets, do not provide a consistent picture of increased (or decreased) leukemia risk in relation to increasing peak or time weighted average (TWA) ELF magnetic field exposure. The data could, however, conceivably be compatible with some more complex biophysical model with unknown properties. Overall, the results of this study provide little evidence supporting the hypothesis that peak or TWA ELF magnetic fields produced by appliances are causally related to the risk of childhood leukemia in children. Bioelectromagnetics 23:14–25, 2002.

Key words: ELF; VLF; appliances; residential; exposure assessment; television sets

INTRODUCTION

A recent epidemiologic study reported associations between childhood leukemia risk and the use of several types of home appliances [Hatch et al., 1998]. Increased incidence of leukemia was found among children whose mothers reported any use of room humidifiers while they were pregnant (odds ratio = 1.42, 95% C.I. = 1.01–1.98) and decreased leukemia risk with maternal use of sewing machines while pregnant (odds ratio = 0.76, 95% C.I. = 0.59–0.98). After birth, leukemia risk was associated with any use by children of hand held hair dryers (odds ratio = 1.55, 95% C.I. = 1.18–2.05) and listening to a stereo system while wearing a headset for at least 3 years prior to the date of diagnosis (odds ratio = 3.04, 95% C.I. = 1.48–6.26). These authors also reported associations between use of television sets for viewing programs or playing video games and leukemia risk; a separate paper [Kaune et al., 2000] addresses this issue.

One possible interpretation of these results is that time weighted average (TWA) exposure to the electric and/or magnetic fields produced by some or all of these appliances is causally related to leukemia risk. However, from an exposure perspective, it is not possible to further evaluate this hypothesis because Hatch et al. [1998] did not measure the magnetic and/or electric fields produced by these appliances.

In a literature review, we identified three independent published studies [Gauger, 1985; Zaffanella, 1993; Preece et al., 1997] that included magnetic field data for some of the home appliances included in our

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study. In the U.S., Gauger [1985] evaluated three hand held hair dryers: At 3 cm from their surfaces, he measured magnetic fields of about 6, 15, and 22 μT. Zaffanella [1993] published data for 95 digital clocks/clock radios and 118 analog clocks/clock radios. At a distance of 27 cm from these units, the median fields were 0.13 μT and 1.5 μT for digital and analog clocks, respectively. Preece et al. [1997] measured the magnetic fields produced by 39 hair dryers and 6 electric clocks used by women living in and near Bristol, England. These authors made an approximate separation of the magnetic fields produced by the appliance under study from fields produced by other sources and reported the means of the magnetic fields at distances of 5 and 50 cm from hair dryers to be 17 and 0.12 μT, respectively, and from electric clocks 5.0 and 0.04 μT, respectively. Since these appliances were manufactured for the European market, where the line voltage is approximately twice that used in the U.S., it is unclear how these data apply to U.S. units.

There were three goals of the research reported in this paper. The first was to measure magnitude and frequency characteristics of the magnetic fields produced by a sample of hand held hair dryers and stereo headsets, used by children and home sewing machines used by their mothers. The second goal was to use these magnetic field data and additional data collected on the patterns of usage of the various appliances to estimate children's TWA exposures, within selected frequency bandwidths, to the magnetic fields produced by the selected appliances. The final goal was to determine if the measured exposures exhibited dose-response patterns that might explain the epidemiologic associations between childhood leukemia and use of the selected home appliances observed by Hatch et al. [1998].

We also collected magnetic field and usage data on electric clocks because of unpublished speculations that sleeping in proximity to electric clocks might lead to elevated exposures to magnetic fields and because Hatch et al. [1998] did observe an elevated, though not statistically significant, leukemia risk (odds ratio = 1.69, 95% C.I. = 0.61–4.65) associated with the use of dial clocks. Data were not collected for room humidifiers used by mothers because we did not believe our study design would be able to identify a large enough sample. We did not measure electric fields because there are few data suggesting that electric field exposure affects cancer incidence or progression in humans or animals [Portier and Wolfe, 1998] and because of the difficulty in and lack of standardization for making electric field measurements that properly take into account the perturbing effect of the bodies of subjects [Kaune and Gillis, 1981; Deno and Silva, 1984; Chartier et al., 1985].

MATERIALS AND METHODS

Subjects and Appliances

The sample consisted of volunteers who were employed by Westat, Inc. or the National Cancer Institute or were recruited to the study by employees of these two organizations. In all, 78 volunteer families with children aged 3–14 years were enrolled in the study during the summer of 1997. Volunteers were selected without reference to the types or numbers of appliances in their homes.

During an initial telephone interview, data collectors ascertained how many hand held hair dryers, stereo headsets, home sewing machines, and electric clocks were currently located in the homes of the subject families. One appliance of each type, if any were present, was selected for inclusion in our study. Generally, if more than one of a type of appliance was present in a home, the oldest was selected because the epidemiological study that prompted our investigation [Hatch et al., 1998] pertained to appliances used during the early 1990s.

The brands and model numbers of the appliances used by the children enrolled in the study of Hatch et al. [1998] were not recorded, so we were not able to gauge quantitatively whether the same appliances were included in our later exposure study. However, we do know that the appliances we included were those purchased for and used by children during the approximate time periods studied by Hatch et al. [1998]. Consequently, we believe it likely that the sample included in our study was representative of appliances used by the subjects of the earlier study.

QUESTIONNAIRE

A trained interviewer administered a brief questionnaire to each mother. The questionnaire collected information on the brand of each appliance and the estimated amount of time that the child used it each day. The typical distances between hair dryers, sewing machines, and clocks and their users were recorded. The usual heat and/or fan-speed settings were recorded for hair dryers. Clocks were divided into two types, those that used internal motors (motorized clocks) and those that did not (electronic clocks). Except for some earlier model clocks that used motors to change numbers, motorized and electronic clocks are the same as analog and digital clocks, respectively.

Magnetic Field Measurements

Instrumentation. We used two different instruments to measure the extremely low frequency (ELF)

(0–3 kHz) and very low frequency (VLF) (8–300 kHz) magnetic fields produced by appliances. Magnetic field waveforms with frequencies in the range 0–3066 Hz were characterized using a Multiwave II Waveform Capture System (Electric Research and Management, State College, PA). This instrument was programmed to measure and retain for later analysis the instantaneous strengths of each of the three vector components (i.e., the *x*, *y*, and *z* components) of magnetic field strength at a sampling rate per component of 6144 Hz (i.e., a sample of the instantaneous magnitude of the component was taken every 0.1628 ms). One complete measurement consisted of 512 individual samples, spanning a time interval of 83.3 ms, of each of the three vector components of the magnetic field. During later analysis, the data resulting from each measurement were Fourier transformed [Mathews and Walker, 1965] to obtain the strengths of the field components with frequencies falling in each of 255 frequency bins, the first extending from 0 to 6 Hz, the second from 6 to 18 Hz, . . . , and the 255th bin from 3054 to 3066 Hz. A "spot" Multiwave II measurement consisted of a sequence of four measurements taken at 10 s intervals.

The Multiwave II system includes a separate fluxgate magnetometer probe connected to the data acquisition electronics by a cable. The sensing element consists of three orthogonal coils, each of axial length ≈ 2 cm, whose centers were positioned within ± 3 cm of each other. The separation and size of the probe elements thus limited the spatial resolution of our measurements to ± 1.5 cm.

The Multiwave II unit was calibrated daily using a Helmholtz system that produced square wave magnetic fields (fundamental frequency of 60 Hz) with root mean square field strengths of 2.5 and 50.0 μT. Accuracy of the magnetic field measurements made with the Multiwave II unit was better than $\pm 5\%$.

We used a second meter (Model HI-3603, Holaday Instruments, Eden Prairie, MN) with a frequency bandwidth extending from 8 to 300 kHz to directly measure the rms *x*, *y*, and *z* components of the VLF magnetic fields produced by appliances. The estimated accuracy of this meter, as specified by the manufacturer, was $\pm 10\%$ assuming its 20 cm diameter probe is used to measure a uniform field. Unfortunately, the fields produced by localized, physically small appliances may have varied substantially over the area of the probe, so the VLF field measurements presented in this paper may have errors appreciably larger than the specified accuracy of the probe.

The instruments available for use in this study did not cover the intermediate frequency region from 3 to 8 kHz. Thus, it is possible that we may not have detected the presence of potentially important field components with frequencies in this range. However, as discussed later, we believe the likelihood of this is small.

Hair dryer protocol. Standardized measurements of the magnetic fields produced by hair dryers were made using a wooden fixture. This fixture held each hair dryer under test at a fixed location and positioned the probe of the Multiwave II magnetic field measurement system at standardized locations (± 0.5 cm) relative to the throat of the nozzle of the dryer under test (Fig. 1). The position of the measurement was specified by the distance along the axis of the hair dryer measured from its nozzle (labeled *x* in Fig. 1) and the transverse distance from the axis (y in Fig. 1). Measurement locations were at $x = 5$, 10, 15, and 25 cm with $y = 0$ cm, and at $y = 5$, 10, and 15 cm with $x = 10$ cm. Multiwave II measurements were made at all 7 locations with each hair dryer operating with its heat and fan speed settings as recorded in the questionnaire and *at* $x = 5$ cm and $x = 25$ cm ($y = 0$ cm) with the hair dryer turned off.

The probe of the VLF magnetic field meter was too large to use with the hair dryer measurement fixture. Consequently, VLF measurements were made at only one point, ≈ 5 cm to the side of the nozzle of the hair dryer under test. The probe was rotated in space until the reading was maximized, and the resulting value recorded.

Headset protocol. A measurement fixture was used to make headset measurements. This fixture was constructed using a model of a young girl's head (originally used to train hair stylists) shown in Figure 2. The model was made of a foam like material. A small microphone element was placed in one ear of

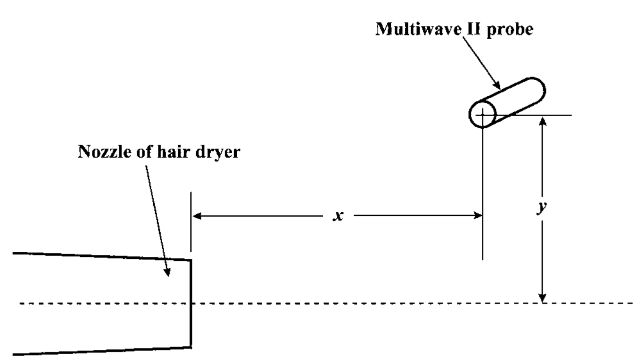

Fig. 1. Diagram of fixture used to position Multiwave II magnetic field probe at locations specified by *x* and *y* coordinates relative to nozzle of hair dryer under test.

the model and was connected to electronics that measured the amplitude of the sound entering this ear. A wooden simulation of the torso of a child was constructed and used to mount the head (Fig. 2). Holes were drilled in the head and torso to accurately position the Multiwave II probe at the following locations: Forehead, between and 4.4 cm above the centers of the eyes, 0.5 cm inside the surface of the head (shown in Fig. 2); center of head, midway between and about 5 cm above the ears; ear, 4.4 cm above the ear, about 0.5 cm inside surface of head; sternum, approximate center (shown in Fig. 2); hip, approximately where a portable tape/CD player would be worn and where it was placed for the model measurements reported in this paper. Magnetic field measurements were taken under 3 conditions. Background: stereo unit turned off. 1 kHz tone: headset powered by a tape player provided by us and playing a tape recorded with a 1 kHz tone with the volume set to yield a fixed reference level from the microphone in the ear. (The reference level was chosen before the beginning of data collection, was used for all the measurements reported in this paper, and corresponded to a comfortable listening level as judged by the first author of this paper.) Music: headset powered by the subject's CD/tape unit playing a musical selection of their choice, with the volume set by them to their normal listening level.

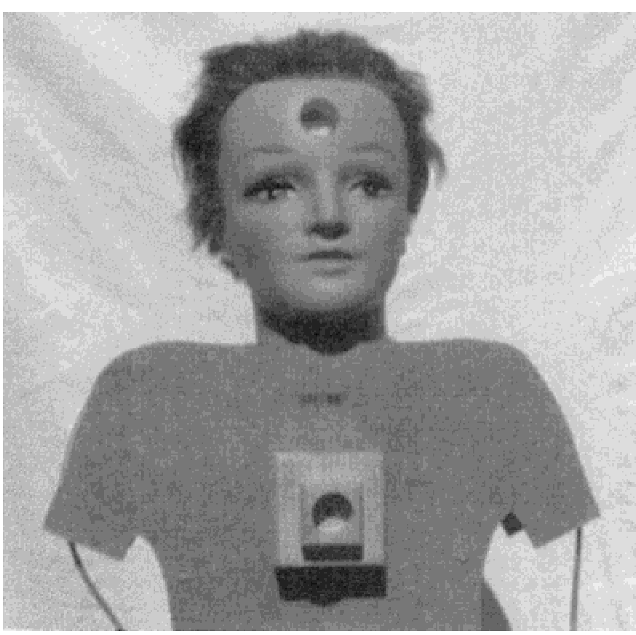

Fig. 2. Photograph of fixture used for headset measurements. Holes drilled in the forehead of the head of the mannequin and in front of the chest positioned Multiwave II probe for forehead and sternum measurements.

Background field measurements were taken at the forehead, sternum, and hip locations. We assume in what follows that the forehead background field can also be used at the center of head and ear measurement locations, since these three locations were very close to each other. One kilohertz tone measurements were taken at all head locations only. We did not make 1 kHz sternum and hip measurements because pilot measurements indicated that the magnetic fields there were partially attributable to the tape player that we provided for all of the 1 kHz measurements. Music measurements were taken at all locations.

The VLF magnetic field probe was too large to use with the headset measurement fixture. Thus, for these measurements, the headset was removed from the fixture and the VLF probe was inserted between the two earphones of headset and rotated for a maximum reading.

Sewing machine protocol. The ELF magnetic fields produced by sewing machines were measured by positioning the Multiwave II probe at three standard locations relative to the body of the user (i.e., the mother) of the sewing machine under test: Front surface of abdomen, approximate height of navel; right side surface of abdomen, approximate height of navel; and left side surface of abdomen, approximate height of navel. Measurements at the front of the abdomen were taken with the sewing machine turned off, turned on but not actually sewing (i.e., idling), and turned on and sewing a seam. Measurements at the sides of the abdomen were made only while the mother was actually sewing.

VLF magnetic fields were measured at the front of abdomen location. The Holaday probe was rotated in space until the reading was maximized, and the resulting value recorded. Measurements were made with the sewing machine first turned off, then turned on with the mother sewing.

Clock protocol. ELF magnetic field measurements were made at fixed horizontal distances of 10, 25, 50, and 100 cm from each clock under test and at a height of 10 cm above the mattress of the bed near which the clock was placed. Distances were determined using a cloth measuring tape to an accuracy of about ± 2 cm. Measurements at horizontal distances of 10 and 100 cm were also made with the clock unplugged from its power source. An additional measurement was made 10 cm above the upper surface of the mattress at the approximate location where the head of the subject would be while they were sleeping. VLF fields were measured only 10 cm horizontally from the clock under test.

Data Analysis

Magnetic field frequency spectra. Every Multiwave II spot measurement yielded a frequency spectrum, i.e., a table or graph of magnetic field strength vs. frequency, of the *x*, *y*, *z*, and resultant field components for each of the four serial measurements. To evaluate the overall shape of the frequency spectra produced by each type of appliance, we computed the mean of the resultant magnetic fields measured at each frequency bin across all spectra for appliances of each type included in our study.

Data summarization and testing. The frequency distribution of magnetic field measurements taken in most environments is generally closer to being log normal than normal [Kaune et al., 1987; Zaffanella, 1993; Bracken et al., 1994; Swanson and Kaune, 1999]. This was also true for the magnetic field data reported in this paper. Consequently, magnetic field data were summarized across appliances and subjects using geometric statistics. Separate analyses were performed for the static component of the magnetic field, i.e., the component whose frequency fell in the frequency bin from 0 to 6 Hz, the sub-power frequency (6–54 Hz), power frequency (54–606 Hz), and supra-power frequency (606–3066 Hz) portions of the ELF band, and the VLF-LF (8–200 kHz) band.

Detailed evaluations showed that the actual distributions of magnetic field data departed from exact log normality. Consequently, all hypothesis testing reported in this paper used nonparametric methods. In particular, the Wilcoxon signed ranks test [Sokal and Rohlf, 1995] was used to test for differences between the *matched* magnetic field measurements taken at various locations relative to appliance sources with the unit under test turned on and then turned off.

Estimation of TWA magnetic field exposure. The percentage contribution of each appliance to total daily TWA magnetic field exposure was estimated assuming that all other exposures were to the background field level at the appliance's location. Let B_{off} be this background field, i.e., the field measured with the appliance turned off, in a specified frequency bandwidth; and let B_{on} be the field measured with the appliance turned on. Assume we wish to calculate TWA exposure during the period T_0 (always set to 24 h in this analysis) and assume the appliance in question was in use by the subject for a period of time ΔT_{A}. TWA exposure $\langle B_{\mathrm{A}}\rangle$ is

$$\begin{aligned}\langle B_{\mathrm{A}}\rangle &= \frac{(T_0-\Delta T_{\mathrm{A}})B_{\mathrm{off}}+\Delta T_{\mathrm{A}}B_{\mathrm{on}}}{T_0}\\ &= B_{\mathrm{off}}+(\Delta T_{\mathrm{A}}/T_0)(B_{\mathrm{on}}-B_{\mathrm{off}}).\end{aligned} \tag{1}$$

TWA exposure $\langle B_{\bar{\mathrm{A}}}\rangle$, assuming the appliance was not used, is B_{off}. Consequently, the fraction of the total exposure to magnetic fields in the specified frequency bandwidth attributable to the appliance in question is

$$\frac{\langle B_{\mathrm{A}}\rangle-\langle B_{\bar{\mathrm{A}}}\rangle}{\langle B_{\mathrm{A}}\rangle}=\left[1+\frac{1}{(\Delta T_{\mathrm{A}}/T_0)(B_{\mathrm{on}}/B_{\mathrm{off}}-1)}\right]^{-1}. \tag{2}$$

RESULTS

Sampling Statistics

Table 1 lists the number of appliances of each type for which magnetic field data were obtained.

Magnetic Field Frequency Spectra

Figure 3 shows selected aggregated magnetic field spectra for each type of appliance included in the study. Spectra shown in the figure are from the locations closest to the appliance under test (so that the appliance field would be strongest) and with appliances turned off (left column in Fig. 3) and on. The background fields exhibited dominant 60 Hz components, with significant levels also at the odd harmonics of 60 Hz (i.e., at 180 Hz, 300 Hz, ...). Some background fields contained low level broadband magnetic field components, i.e., components at all frequencies. With hair dryers turned on, magnetic fields measured 5 cm from their nozzles were markedly elevated over background levels (first row of Fig. 3) and contained even as well as odd harmonics of 60 Hz.

The observation of substantial even harmonics in the magnetic field spectra of hair dryers was evaluated further. The three rows of graphs in Figure 4 show the *x*, *y*, and *z* component waveforms for three hair dryers.

TABLE 1. Number of Appliances of Various Types for Which Magnetic Field Data Were Obtained.

Appliance	Number
Hand-held hair dryer	37
Head set	28
Sewing machine	19
Motorized electric clock	2
Electronic clock	28

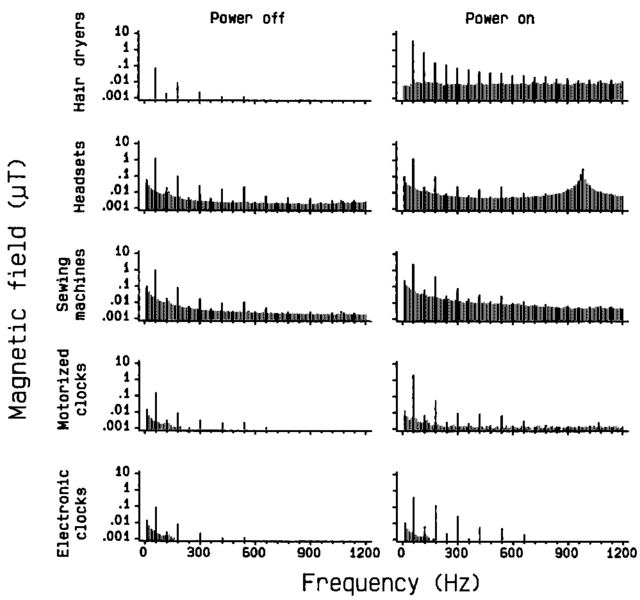

Fig. 3. Appliance frequency spectra taken at locations close to appliances with the appliance turned off, then on. The power on spectra for headsets was taken while playing a 1000 Hz tone.

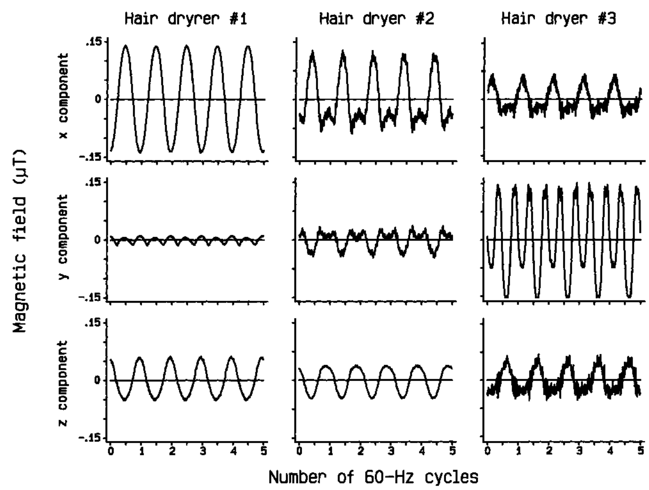

Fig. 4. Waveforms of *x, y,* and *z* components of magnetic fields measured 5 cm from the nozzles of three hair dryers.

The waveforms for the first hair dryer (left column of Fig. 4) are largely sinusoidal, indicating that only 1 frequency (60 Hz) was dominant. However, some of the component waveforms for the other 2 dryers exhibit considerable asymmetry between their positive and negative halves. It can be shown that such positive-negative asymmetry can occur if and only if the magnitude of at least one even harmonic is nonzero.

The power-on headset spectra in the right hand graph in the second row of Figure 3 was taken while playing a cassette tape with a prerecorded 1 kHz tone. This tone produced a local peak in the magnetic field spectrum at 1 kHz. For the other appliances included in the study (sewing machines and clocks), the spectra taken with units turned on were very similar in shape to those taken with them turned off.

Magnetic Field Strengths

Tables 2–6 list geometric means summarizing static, ELF, and VLF magnetic fields measured near hand held hair dryers, stereo headsets, home sewing machines, and motorized and electronic clocks.

The geometric mean static magnetic field measured 5 cm from hair dryers was 55 μT, regardless of whether the unit was turned on or off (Table 2). Interestingly, the static fields measured at locations further from the nozzles of dryers were about 10% smaller, suggesting that hair dryers may contribute to the static field in their vicinity, regardless of whether they are turned on or off. This may be due to local field increases around the ferromagnetic materials in the motors of hairdryers that are used to power their fans. The geometric mean ELF (6–3066 Hz) magnetic field at 5 cm increased from a background level of 0.07–4.2 μT, when dryers were turned on. Most of the increase in field strength was concentrated in the power frequency range (54–606 Hz), but levels were also significantly increased in the sub- (6–54 Hz) and supra-power frequency (606–3066 Hz) ranges. The VLF (8–200 kHz) magnetic field was also substantially increased at 5 cm. At larger distances from the nozzles, increases in ELF and VLF magnetic field strength that occurred when dryers were turned on were smaller. For example, at the largest distance tested in our study (25 cm), the geometric mean power frequency (54–606 Hz) magnetic field was 0.07 μT before dryers were turned on and 0.23 μT after they were turned on.

We next turn to magnetic field data for headsets (Table 3). Geometric mean static magnetic fields produced by headsets at the three measurement locations in the head (forehead, center of head, above the ear, Fig. 2) were higher, compared to background levels, when these units were used to listen to either a 1 kHz tone or music. Interestingly, AC magnetic field components in the 54–606 Hz frequency bin, which included the major components of the background field, were not significantly higher than background levels at any of the five measurement locations when headsets were used to listen to music. Geometric mean magnetic fields in the other frequency bands in the ELF region were altered slightly from background levels when headsets were used to listen to music, even at the sternum and hip locations. The largest increase in field

TABLE 2. Geometric Means of Magnetic Fields Measured at Selected Distances From 37 Hand Held Hair Dryers. The Wilcoxon Signed Ranks Test was Used to Compare Magnetic Fields Measured at Distances of 5 and 25 cm From Hair Dryers Turned off, Then on.

	Distance from dryer		Geometric mean magnetic field (μT)				
Dryer status	Axial (cm)	Transverse (cm)	Static (0–6 Hz)	Sub-power frequency (6–54 Hz)	Power frequency (54–606 Hz)	Supra-power frequency (606–3066 Hz)	VLF (8–200 kHz)
Off	5	0	55.3	0.0016	0.073	0.0029	0.033
On	5	0	55.0	0.0133[a]	4.15[a]	0.220[a]	0.360[a]
On	10	0	51.5	0.0053	1.256	0.0901	—
On	15	0	50.5	0.0036	0.579	0.0479	—
Off	25	0	50.4	0.0018	0.074	0.0030	—
On	25	0	50.3	0.0026[b]	0.228[a]	0.0182[a]	—
On	10	5	51.3	0.0051	1.092	0.0845	—
On	10	10	50.9	0.0042	0.779	0.0697	—
On	10	15	50.8	0.0034	0.542	0.0553	—

"—" indicates no measurement was made at this location.
[a]$P < 0.0001$.
[b]$0.01 \leq P \leq 0.05$.

strength occurred at the hip location and was due to fields produced by the tape player used to energize the headsets. VLF magnetic fields were not significantly altered when headsets were in use.

Static magnetic fields measured near the abdomens of women using home sewing machines were the same, regardless of whether the sewing machine was turned on or off (Table 4). Geometric mean AC magnetic fields were not altered significantly when sewing machines were turned on, but were significantly increased at the front surfaces of the abdomens of mothers when they were using sewing machines to sew seams. Geometric mean magnetic fields measured at the side surfaces of the abdomens of mothers were increased slightly. VLF magnetic fields were not altered by sewing machine use.

Since our sample of motorized clocks included only two units, our ability to statistically detect changes in magnetic field levels associated with their operation was severely limited. However, examination of the data in Table 5 shows that the geometric mean ELF magnetic field at 10, 25, and 50 cm from these

TABLE 3. Geometric Means of Magnetic Fields Measured at Selected Location Produced by 28 Stereo Headsets. The Wilcoxon Signed Ranks Test was Used to Compare Magnetic Fields Measured at Head, Sternum, and Hip Locations With Headsets Either not in Use, Being Used to Listen to a 1000 Hz Tone, or Being Used to Listen to Music.

		Geometric mean magnetic field (μT)				
Headset status	Measurement location	Static (0–6 Hz)	Sub-power frequency (6–54 Hz)	Power frequency (54–606 Hz)	Supra-power frequency (606–3066 Hz)	VLF (8–200 kHz)
Off	Forehead	50.8	0.0066	0.122	0.0034	0.0023
Playing tone	Forehead	54.6[c]	0.0077	0.119	0.0058[a]	—
Playing tone	Center head	58.4[d]	0.0020[a]	0.121	0.0100[a]	—
Playing tone	Above ear	93.2[b]	0.0111[c]	0.123	0.0445[a]	—
Playing music	Forehead	54.6[c]	0.0099[c]	0.117	0.0042[c]	—
Playing music	Center head	58.3[d]	0.0032[c]	0.119	0.0040	0.0025
Playing music	Above ear	92.7[a]	0.0130[b]	0.118	0.0085[b]	—
Off	Sternum	50.7	0.0050	0.121	0.0031	—
Playing music	Sternum	50.4	0.0069[d]	0.117	0.0034[d]	—
Off	Hip	50.2	0.0093	0.124	0.0033	—
Playing music	Hip	53.5	0.0252[c]	0.118	0.0087[b]	—

"—" indicates no measurement at this location.
[a]$P < 0.0001$.
[b]$0.0001 \leq P < 0.001$.
[c]$0.001 \leq P < 0.01$.
[d]$0.01 \leq P < 0.05$.

TABLE 4. Geometric Means of Magnetic Fields Measured at Selected Location Produced by 19 Home Sewing Machines. The Wilcoxon Signed Ranks Test was Used to Compare Magnetic Fields Measured at the Front of the Abdomen With Sewing Machines Either off, Turned on but not Actually Sewing (Idling), or Turned on and Sewing a Seam.

		Geometric mean magnetic field (μT)				
Sewing machine status	Measurement location	Static (0–6 Hz)	Sub-power frequency (6–54 Hz)	Power-frequency (54–606 Hz)	Supra-power frequency (606–3066 Hz)	VLF (8–200 kHz)
Off	Front of abdomen	52.1	0.0111	0.094	0.0029	0.0018
On, idling	Front of abdomen	52.1	0.0105	0.110	0.0030	—
On, sewing	Front of abdomen	52.4	0.0297[a]	0.261[a]	0.0070[a]	0.0027
On, sewing	Right side of abdomen	52.3	0.0189	0.184	0.0051	—
On, sewing	Left side of abdomen	52.0	0.0185	0.150	0.0043	—

"—" indicates no measurement at this location.
[a]$0.0001 < P < 0.001$.

units were higher than background levels by factors of 12, 3.8, and 1.6, respectively. Given that motorized clocks use electric motors which are known sources of magnetic fields, we conclude that this type of clock does increase magnetic fields levels within about 50 cm. VLF magnetic fields do not appear to be affected.

Static magnetic fields were not altered when electronic clocks were turned on, but were somewhat larger at 10 cm than at the larger measurement distances, regardless of whether the clocks were connected to a source of electric power (Table 6). At a distance of 10 cm, power frequency (54–606 Hz) magnetic fields were significantly increased over background levels where clocks were plugged in to a source of electric power. There was no effect on magnetic field levels at 100 cm when clocks were plugged in. VLF magnetic fields at 10 cm were slightly increased, compared to ambient levels, when electronic clocks were in operation.

Evaluation of Exposure to Magnetic Fields Produced by Appliances

In this section we estimate the exposures of children to the magnetic fields produced by hand held hair dryers, stereo headsets, and bedroom electric clocks, and the exposures of mothers to the magnetic fields produced by sewing machines. Tables 7 and 8 were prepared to help in this evaluation. Table 7 lists ratios of the magnetic fields measured with appliances turned on and off. Unfortunately, appliance off magnetic fields were not measured at all locations where appliance on fields were measured. Thus, missing appliance off fields were estimated by linearly extrapolating from measured values at the nearest 2 locations. Table 8 lists the percentages of daily TWA

TABLE 5. Geometric Means of Magnetic Fields Measured at Selected Distances From 2 Motorized Clocks (i.e., Clocks That Use a Motor to Operate Their Hands). The Wilcoxon Signed Ranks Test was Used to Compare Magnetic Fields Measured at Distances of 10 and 100 cm From Clocks Turned off, Then on.

		Geometric mean magnetic field (μT)				
Clock status	Distance from clock (cm)	Static (0–6 Hz)	Sub-power frequency (6–54 Hz)	Power frequency (54–606 Hz)	Supra-power frequency (606–3066 Hz)	VLF (8–200 kHz)
Off	10	57.8	0.0162	0.153	0.0045	0.0014
On	10	55.5	0.0153	1.972	0.0195	0.0016
On	25	55.5	0.0075	0.608	0.0031	—
On	50	52.5	0.0028	0.252	0.0027	—
Off	100	50.6	0.0043	0.145	0.0027	—
On	100	50.6	0.0022	0.145	0.0027	—
On	Head	52.7	0.0016	0.210	0.0027	—

"—" indicates no measurement at this location.

TABLE 6. Geometric Means of Magnetic Fields Measured at Selected Distances From 28 Electronic Clocks (i.e., Clocks That do not Use Motors). The Wilcoxon Signed Ranks Test was Used to Compare Magnetic Fields Measured at Distances of 10 and 100 cm From Clocks Turned off, Then on.

		Geometric mean magnetic field (μT)				
Clock status	Distance from clock (cm)	Static (0–6 Hz)	Sub-power frequency (6–54 Hz)	Power frequency (54–606 Hz)	Supra-power frequency (606–3066 Hz)	VLF (8–200 kHz)
Off	10	61.6	0.0155	0.085	0.0037	0.0020
On	10	60.7	0.0125	0.397[a]	0.0055[b]	0.0030[c]
On	25	52.5	0.0065	0.151	0.0036	—
On	50	54.2	0.0021	0.086	0.0029	—
Off	100	54.1	0.0017	0.078	0.0028	—
On	100	54.2	0.0018	0.078	0.0029	—
On	Head	54.3	0.0019	0.088	0.0028	—

"—" indicates no measurement at this location.
[a] $P < 0.0001$.
[b] $P = 0.012$.
[c] $P = 0.049$.

ELF magnetic field exposures attributable to each type of appliance; these percentages were calculated using Eq. (2) with values for B_{on}/B_{off} taken from Table 7 and using values for the daily time appliances were in use [i.e., ΔT_A in Eq. (2)] from the study questionnaire. TWA exposure calculations were not attempted for VLF magnetic fields because of the limited scope of these data.

Hair dryers. Thirty-three parents responded on the questionnaire for this project with estimates of the distances their children held the nozzles of their hair dryers from their heads while drying their hair. The mean distance was 9.7 cm (SD = 4.8 cm). Mothers estimated their children spent an average of 2.6 min (SD = 2.7 min, max = 10 min) per day using hair dryers. Using these data, Table 8 lists the percentage

TABLE 7. Ratios (B_{on}/B_{off}) of Magnetic Fields Measured With Appliances Turned on and off. B_{off} was Estimated Using Linear Interpolation at Those Measurement Location Where it was not Directly Measured.

		B_{on}/B_{off}			
Appliance	Measurement location	6–54 Hz	54–606 Hz	606–3066 Hz	8–200 kHz
Hair dryer	5 cm from nozzle	8.3	57	76	11
	10 cm from nozzle	3.2	17	31	—
	15 cm from nozzle	2.1	7.9	16	—
	25 cm from nozzle	1.4	3.1	6.1	—
Headset playing music	Forehead	1.5	1.0	1.2	—
	Center of head	< 1.0	1.0	1.2	1.1
	Above ear	2.0	1.0	2.5	—
	Sternum	1.4	1.0	1.1	—
	Hip	2.7	1.0	2.6	—
Home sewing machines	Front of abdomen	2.7	2.8	2.4	1.5
	Left side of abdomen	1.7	2.0	1.8	—
	Right side of abdomen	1.7	1.6	1.5	—
Motorized clock	10 cm from clock	< 1.0	13	4.3	1.1
	25 cm from clock	< 1.0	4.0	< 1.0	—
	50 cm from clock	< 1.0	1.7	< 1.0	—
	100 cm from clock	< 1.0	1.0	1.0	—
	At subject's head	< 1.0	1.4	1.0	—
Electronic clock	10 cm from clock	< 1.0	4.7	1.5	1.5
	25 cm from clock	< 1.0	1.8	1.0	—
	50 cm from clock	< 1.0	1.1	< 1.0	—
	100 cm from clock	1.1	1.0	1.0	—
	At subject's head	1.1	1.1	1.0	—

contributions to background TWA magnetic fields attributable to hair dryer use by an average child. The estimated percentage in the 54–606 Hz frequency range is 2.8%; since the dominant fields in the entire ELF range occur in this bandwidth, we may infer with good confidence that hair dryer use will elevate daily background TWA ELF magnetic field exposures by about 3%. The impact of hair dryer use is somewhat larger (5.1%) in the 606–3066 Hz frequency band because hair dryers do produce magnetic fields in this band (Fig. 3) where the ambient fields are quite small.

Stereo headsets. According to 26 mothers' estimates, the daily time of usage of headsets was about 19 min (SD = 35 min, maximum = 180 min). Background TWA magnetic field exposure in the 54–606 Hz frequency band was not substantially elevated by headset use (Table 8). At the measurement location closest to the headset (i.e., above the ear), headsets contributed 1.3 and 1.9%, respectively, to 6–54 Hz and 606–3066 Hz TWA exposure. We were able to detect headset contributions in these frequency ranges only because ambient fields were so low.

Home sewing machines. Eighteen mothers who responded to the study questionnaire reported an average daily sewing machine use of 17 min (SD = 43 min, maximum = 180 min). On a daily basis, average sewing machine use will contribute about 2% at the front of the abdomen and about 0.6–1.0% at the sides of the abdomen to daily background TWA magnetic field exposure.

Electronic clocks. Mothers estimated the average daily time their children were located within 122 cm (4 feet) of electronic clocks to be 9 h (SD = 3 h, maximum = 17 h). At the location of a sleeping child's head, magnetic fields were not distinguishable from ambient background levels (Table 6). Consequently, we can conclude that the use of electronic clocks will not contribute materially to daily background TWA magnetic field exposure.

SUMMARY AND DISCUSSION

The data presented in this paper show that hair dryers substantially elevated ELF and VLF magnetic field levels in their vicinity. For example, at 10 cm, the mean of the distances mothers estimated hair dryers were held from the head by children, the 54–606 Hz and 606–3066 Hz magnetic fields with hair dryers turned on were 17 and 31 times larger, respectively, than when hair dryers were turned off (Table 7). Furthermore, the shape of the frequency spectra was substantially altered, when hair dryers were turned on, by the introduction of even harmonic components of 60 Hz (Fig. 3). Even though hair dryers produce rather intense magnetic fields compared to ambient levels, the average estimated daily use of 2.6 min/day was sufficiently small to make the contributions of these units to average daily TWA magnetic field exposures less than about 5% (Table 8).

We found that 54–606 Hz magnetic field exposures to the head, sternum, and hip were not measurably altered when stereo headsets were in use by children (Table 7), because the magnetic fields produced by these devices were small in comparison to normal ambient 60 Hz levels. We did observe some alteration in magnetic field levels in the 6–54 Hz and 606–3066 Hz frequency bands, but magnetic field levels with headsets either in or not in operation were quite small. Mean daily headset usage was estimated to be about 19 min, and contributions of headsets to daily TWA ELF magnetic field exposures were estimated to be quite small (Table 8).

Our measurements showed that sewing machine used by mothers while they were pregnant does produce ELF and VLF magnetic field levels in the abdominal area of the body of the user that are measurably elevated above ambient levels (Table 7). However, the amount of elevation is not large (ratio of appliance on to appliance off field strength ≤ 2.8) and, since mothers in our study report using their sewing machines on average only about 17 minutes per day, average daily TWA magnetic field exposure is only minimally affected by sewing machine use (Table 8). It is also noteworthy that the shape of the frequency spectrum of the magnetic fields present, when sewing machines are in use, is not materially different from that when sewing machines are not in use (Fig. 3).

Motorized clocks produced magnetic fields stronger than ambient levels within distances of about 50 cm. Unfortunately, our sample was too small to enable us to reach any definite conclusion concerning the contributions of this type of source of TWA magnetic field exposure.

Our sample did include a substantial number (28) of electronic clocks placed near the beds of subjects. However, we found that the mean distances between these sources and subjects when they were in their vicinity (usually while sleeping) was sufficiently large (122 cm) to render the magnetic fields when electronic clocks were turned on not measurably different from levels when clocks were turned off. Consequently, our data do not support the idea that, in general, electric clocks are a significant source of magnetic field exposure for children.

TABLE 8. Percent Increase in Background TWA Exposure Attributable to Use of Indicated Appliance.

Appliance	Measurement location	Daily use (min)	Percentage increase of TWA exposure		
			6–54 Hz	54–606 Hz	606–3066 Hz
Hair dryer	Surface of head	2.6	0.4	2.8	5.1
Headset playing music	Forehead	19	0.7	0.0	0.3
	Center of head		0.0	0.0	0.3
	Above ear		1.3	0.0	1.9
	Sternum		0.5	0.0	0.1
	Hip		2.2	0.0	2.1
Home sewing machines	Front of abdomen	17	2.0	2.1	1.6
	Left side of abdomen		0.8	1.2	0.9
	Right side of abdomen		0.8	0.7	0.6
Electronic clock	At subject's head	540	≈1.0	≈1.0	0.0

Hatch et al. [1998] reported associations between television use and pediatric leukemia risk. A separate paper [Kaune et al., 2000] presents our results for this appliance. In the latter paper, we concluded that "... our results provide little support for a linkage between childhood leukemia and exposure to the ELF magnetic fields produced by TV sets." This conclusion was based on the following observations: (1) The ELF fields produced by TV sets were very small at the locations where children generally resided while watching programs or playing video games: In the frequency bands 6–54 Hz and 54–606 Hz, magnetic field levels were indistinguishable from the ambient, whereas in the 606–3066 Hz and 8–200 kHz bands, magnetic field levels were modestly elevated when TV's were turned on but were very small in absolute magnitude. (2) Children who watched TV sets more than 6 h/day while sitting either <4 feet or ≥ 6 feet from their TV sets had about equal risks of contracting leukemia, even though exposures for the former group would have been markedly larger than for the latter [Kaune et al., 2000].

Unfortunately, because of instrumentation limitations, our measurements would have detected only with reduced sensitivity magnetic field components with frequencies between 3 and 8 kHz. We do not believe this exclusion is a serious limitation to our study because there is nothing in our data, nor in the design of the appliances of interest, that suggests that 3–8 kHz frequency spectra would have been anything more than smooth curves connecting the lower to the higher frequency spectra.

A simple monotonic dose response model relating peak or TWA magnetic field exposure resulting from appliance use and leukemia risk would require that increasing field strength, and/or increasing daily duration of exposure, are associated with increased leukemia risk. Our data are not consistent with this picture. For example, brief daily exposures of children to the fairly strong magnetic fields from hair dryers was associated with a modestly elevated risk (odds ratio = 1.6) [Hatch et al., 1998], whereas slightly longer daily exposure to the markedly weaker fields produced by stereo headsets was associated with a considerably stronger level of risk (odds ratio = 3.0) [Hatch et al., 1998]. Furthermore, maternal prenatal exposure to the magnetic fields produced by sewing machines was associated with *reduced* pediatric leukemia risk [Hatch et al., 1998]. Finally, as noted earlier, children who watched TV the most seemed to have about equal leukemia risk regardless of their level of magnetic field exposure.

It is, however, possible that childhood leukemia risk may be related to some other aspect of magnetic field exposure, such as the strength of the 606–3066 Hz or VLF magnetic fields, and/or with a nonmonotonic (e.g., windowed) dose response curve that could explain the observed results. However, such a hypothesis is complex, would require a very high level of biological sensitivity to magnetic fields because of the low strengths of the fields in question, and is not consistently supported by laboratory data [Portier and Wolfe, 1998]. We thus conclude that the results of our appliance measurements do not provide much support for the hypothesis that the ELF magnetic fields produced by home appliances are causally related to increased leukemia risk in children.

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REFERENCES

Bracken TD, Rankin RF, Senior RS, Alldredge JR. 1994. The EMDEX Project: Residential Study. Volume 1: Summary. EPRI Report TR-104325-V1, Electric Power Research Institute, Palo Alto, CA.

Chartier VL, Bracken TD, Capon AS. 1985. BPA study of occupational exposure to 60 Hz electric fields. IEEE Trans Power Apparatus Systems PAS-104:733–744.

Deno DW, Silva JM. 1984. Method for evaluating human exposure to 60 HZ electric fields. IEEE Trans Power Apparatus Systems PAS-103:1699–1706.

Gauger JR. 1985. Household appliance magnetic field survey. IEEE Trans Power Apparatus Systems PAS-104:2436–2444.

Hatch EE, Linet MS, Kleinerman RA, Tarone RE, Severson RK, Hartsock CT, Haines C, Kaune WT, Friedman D, Robison LL, Wacholder S. 1998. Association between childhood acute lymphoblastic leukemia and use of electrical appliances during pregnancy and childhood. Epidemiology 9:234–245.

Kaune WT, Gillis MF. 1981. General properties of the interaction between animals and ELF electric fields. Bioelectromagnetics 2:1–11.

Kaune WT, Stevens RG, Callahan NJ, Severson RK, Thomas DB. 1987. Residential magnetic and electric fields. Bioelectromagnetics 8:315–335.

Kaune WT, Miller MC, Linet MS, Hatch EE, Kleinerman RA, Wacholder S, Mohr AH, Tarone RE, Haines C. 2000. Children's exposure to magnetic fields produced by U.S. television sets used for viewing programs and playing video games. Bioelectromagnetics 21:214–227.

Mathews J, Walker RL. 1965. Mathematical Methods of Physics. New York: W.A. Benjamin, Inc.

Portier CJ, Wolfe MS. 1998. Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields. NIH Publication 98-3981, National Institute of Environmental Health Sciences, Research Triangle Park, NC.

Preece AW, Kaune W, Grainger P, Preece S, Golding J. 1997. Magnetic fields from domestic appliances in the UK. Phys Med Biol 42:67–76.

Sokal RR, Rohlf FJ. 1995. Biometry. New York: W.H. Freeman and Company.

Swanson J, Kaune WT. 1999. A comparison of residential power frequency magnetic fields away from appliances in different countries. Bioelectromagnetics 20:244–254.

Zaffanella LE. 1993. Survey of Residential Magnetic Field Sources. Volume 1: Goals, Results, and Conclusions. Report TR-102759-V1, Electric Power Research Institute, Palo Alto, CA.